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## **MOISTURE TRANSPORT PROPERTIES OF BRICK – COMPARISON OF EXPOSED, IMPREGNATED AND RENDERED BRICK**

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### **Abstract**

In regards to internal insulation of preservation worthy brick façades, external moisture sources, such as wind-driven rain exposure, inevitably has an impact on moisture conditions within the masonry construction. Surface treatments, such as hydrophobation or render, may remedy the impacts of external moisture. In the present paper the surface absorption of liquid water on masonry façades of untreated, hydrophobated and rendered brick, are determined experimentally and compared. The experimental work focuses on methods that can be applied on-site, Karsten tube measurements. These measurements are supplemented with results from laboratory measurements of water absorption coefficient by partial immersion. Based on obtained measurement results, simulations are made with external liquid water loads for determination of moisture conditions within the masonry of different surface treatments. Experimental results showed a very clear reduction of the liquid water uptake for hydrophobated cases. However, hygrothermal simulations demonstrated clear differences in the effect of the surface treatments on the moisture content of brick depending on the brick type.

### **1. Introduction**

Several studies have shown that external moisture sources, such as wind-driven rain (WDR), penetrate – especially thinner - masonry constructions. This inevitably influences the hygrothermal conditions of an internally insulated masonry building, which can essentially lead to health problems of inhabitants or general building degeneration. A single-leaf, untreated brick wall with high WDR loads was simulated and elevated relative humidities on internal walls were found, both with and without insulation [1]. Determination of WDR loads

and hygrothermal impact on solid brick walls has been conducted by hygrothermal simulations. The study showed, that WDR had a distinct impact on the relative humidity on the interior wall surfaces – especially during winter and summer [2]. Another study has also demonstrated the impact of WDR on the relative humidity in a masonry construction – in this case an embedded wooden beam. The study displayed critically high humidity conditions in beam ends, in cases with high rain intensity – based on hygrothermal simulations [3]. A significant impact of the magnitude of WDR loads on moisture conditions in the beam ends, has also been proven by 2D and 3D simulations [4]. The water uptake through the external surface must therefore be seen as a vital parameter for water penetration through the masonry.

The water absorption can be obstructed/limited by various means; render, paint, hydrophobisation, or water repelling surface treatment. Künzle [5] recommends a water repelling surface treatment before implementation of internal insulation, as the drying capacity and thermal resistance in the masonry is reduced by the hygrothermal changes following internal insulation, which can cause not only undesirable moisture conditions on the internal wall, but also frost damage to the façade. The impact of a hydrophobisation treatment on internally insulated walls has been documented by simulations, e.g. in [6]. The study included several cases with both capillary active and inactive insulation solutions on a 1-brick thick wall. Results showed significantly improved hygrothermal conditions in the masonry and humidity at the interface between insulation and original wall, in cases with external hydrophobisation treatment – also illustrating the impact of WDR [6].

In this present study, laboratory experiments were carried out in order to determine to which extent some guards of weather protection can limit the water absorption compared to untreated brick. The studied surface treatments were rendered and hydrophobisation. The water uptake was studied by means of Karsten tube and partial immersion methods. The results were supplemented by hygrothermal simulations for long term exposure and for the effect of different brick types beside the studied surface treatments. Water absorption through joints and mortar was not studied, even though it is acknowledged that penetration through these parts of masonry may be significant.

## 2. Materials and Methods

### 2.1 Materials

For laboratory experiments, three types of samples were used; 5 test specimens were rendered, 5 specimens were hydrophobized and the surfaces of 5 specimens were left untreated; these were used as reference specimens. A list of the components used for the test specimens are given in Table 1.

Table 1. The components used for test samples.

Brick	Yellow soft-molded brick from Helligsø Teglværk in Sydthy
Render	Standard 7.7% lime adjusted wet mortar, grain size 0-4mm (air lime)
Hydrophobisation	Funcosil FC from Remmers

The bricks were stored at a stationary indoor climate corresponding to the test conditions specified in prEN ISO 15148:2002 [7], until reaching a constant mass, i.e. the mass is not changing more than 0.1 % in 24 hours. Hereafter, 5 specimens were surface treated with air

lime render (approximately 1 cm thick) and 5 specimens with Funcosil hydrophobation (approximately 0.36 l/m<sup>2</sup>) respectively. Before laboratory experiments were carried out, the specimens should obtain constant conditions again, and it was ensured that the lime render was completely carbonated. The rendered specimens were placed in a climate chamber with a CO<sub>2</sub>-supply in order to accelerate the carbonization process. The carbonation process was monitored by phenolphthalein on extra specimens. The hydrophobated specimens were tested 6 weeks after Funcosil application, according to manufacturer's recommendations.

## 2.2 Methods

The Karsten tube method is a non-destructive measuring method that can be implemented on in situ bricks. Mainly, Karsten tube measurements are performed for comparison purposes. Calculation methods developed by Roel Hendrickx [8] adds the option for conversion to sorptivity. Karsten tube experiments were carried out vertically on all specimens, and calculations performed according to the method described by Roel Hendrickx [8]. The specimens were subjected to demineralized water in the 4 ml tubes fixed to the center of the surface vertically. The water uptake was noted at 5 minute intervals for 30 minutes. The diameter of the contact area was registered individually, as variations occur due to the fixation. The diameter of the wetted area was measured at termination of each experiment, as the wet area became visible when removing tube and fixation. The calculations provided and described in [8] yield the value for sorptivity by the following calculations:

$$x(t) = R_{wet}(t) - \frac{D_e}{2} \quad (1)$$

$x(t)$ : penetration of wet front at time  $t$  [mm]

$R_{wet}$ : radius of effective contact area [mm]

$D_e$ : diameter of wet area [mm]

$$V_{wet}(t) = \frac{2}{3} \cdot \pi \cdot (x(t)^3 + R_e \cdot x(t)) + \pi \cdot R_e^2 \cdot x(t) \quad (2)$$

$V_{wet}(t)$ : wet volume at time  $t$  [mm<sup>3</sup>]

$$\theta_{cap}(t) = \frac{V_{abs}(t)}{V_{wet}(t)} \quad (3)$$

$\theta_{cap}(t)$ : capillary saturated volume moisture content at time  $t$  [mm<sup>3</sup>/mm<sup>3</sup>]

$V_{abs}(t)$ : absorbed volume at time  $t$  [ml].

$$V_{abs} = \pi \cdot R_e^2 \cdot S \cdot \sqrt{t} + \frac{\pi \cdot R_e \cdot \gamma \cdot S^2}{\theta_{cap}} \cdot t \quad (4)$$

$S$ : sorptivity [cm/ $\sqrt{\text{min}}$ ]

$\gamma$ : empirical factor of 0.75

The sorptivity is obtained by solving for  $S$  in Eq. 4, and finding the average of all times. Multiplying with  $\frac{10}{\sqrt{60}}$  yields the common unit of sorptivity,  $S$ ; [ $\frac{\text{kg}}{\text{m}^2 \cdot \sqrt{\text{s}}}$ ]. As previously implied, the wetted diameter could only be measured by the end of the experiment, hence no average value for the time can be found, however  $\theta_{cap}$  should be a constant material parameter, why the value at termination, 30 minutes, is assumed and calculated.

After Karsten tube measurements, the specimens were dried until constant mass again was assumed. Epoxy was applied as a water and vapour tight sealant to the 4 sides of each stone, leaving the end surfaces blank, for water absorption by partial immersion.

For determination of short-term water absorption coefficient, the method described in prEN ISO 15148:2002 [7] was implemented. It was ensured that the test specimens were free of irregularities on the absorption surface, and had a water contact area larger than 50cm<sup>2</sup>, as prescribed in the standard. Again, the specimens were conditioned until each mass was stabilized within 0.1 % of the mass within 24 hours.

The experiment was carried out as described here; each specimen was weighed with a scale of  $\pm 0.1$  % accuracy, and the initial mass registered as  $m_i$ . A water tank, capable of maintaining a constant water level, was filled with water, and specimens were placed in the tank, on point supporters. The water level was kept at  $5 \pm 2$  mm above the base of the test specimen. A timer (accurate to 1 second) was started, as the specimens were immersed in water. 5 minutes after immersion, for each specimen, they were removed from the water, the surface blotted dry, the weight registered,  $m_{5min}$ , and the specimen put back in the tank. This procedure was repeated at time steps of 20 minutes, 1 hour, 2 hours, 4 hours, 8 hours, 9 hours and a last weighing 24 hours after initial immersion. The mass difference between each weighing relative to initial mass per area,  $\Delta m_t$ , is plotted against the square root of time. The curvature indicates the calculation method for obtaining the water absorption coefficient,  $A_w$ .

In cases where the graph results in a suddenly occurring straight, horizontal line, indicating liquid water at the specimen surface, the water absorption coefficient is calculated by the following method;

A linear trend line is placed through the initial results for  $\Delta m_t$ , until the slope's sudden decline. The value of  $\Delta m_t$  cuts the y-axis, is denoted  $\Delta m'_0$ .

$$A_w = \frac{\Delta m'_{t_f} - \Delta m'_0}{\sqrt{t_f}} \quad (5)$$

$t_f$ : duration of experiment [s]

$\Delta m'_{t_f}$ : value of  $\Delta m_t$  at time  $t_f$  [kg/m<sup>2</sup>]

In cases where the plot yields a curve, the calculations are made according to eq. 6;

$$A_{w,24} = \frac{\Delta m_{24}}{\sqrt{86400}} \quad (6)$$

$A_{w,24}$ : water absorption coefficient related to 24 hours [kg/m<sup>2</sup>s<sup>1/2</sup>]

$\Delta m_{24}$ : mass gain per face area after 24 hours [kg/m<sup>2</sup>].

### 2.3 Simulations

The effect of surface treatment was also studied with hygrothermal dynamic simulations. One-dimensional models in calculation tool Delphin [11] were constructed and simulations were performed on various brick types with hydrophobisation, render and no surface treatment. The brick types investigated numerically were Brick Joens and Brick Bernhard, and Brick Schlagmann from the Delphin material database, as well as the yellow brick used in

experiments. The material parameters of yellow brick were partly based on Delphin database Historical Brick (cluster 4) and partly on experimental values obtained by Sandholdt et. al. (2015) [9]. The simulations were performed on bricks of 228mm thickness, corresponding to a 1-brick thick external wall, typical in e.g. parapets or gables in historic Danish buildings. The render was a lime plaster (historical) with 1cm thickness. Material properties of the investigated brick types and the lime render are summarized in Table 2. In an attempt to simulate a hydrophobated surface treatment, the exterior 5mm of the brick was given a water uptake coefficient reduced by factor 15 – the factorial difference found between reference specimens and specimens with hydrophobisation treatment in Karsten tube experiments (see Results section).

Table 2. Material parameters for materials in Delphin simulations.

Material	Density [kg/m <sup>3</sup> ]	Thermal conductivity [W/mK]	Vapour diffusion resistance factor [-]	Open porosity [m <sup>3</sup> /m <sup>3</sup> ]	Water uptake coefficient [kg/m <sup>2</sup> s <sup>1/2</sup> ]
Brick Joens	1790	0.87	14	0.36	0.23
Brick Bernhard	2060	1.00	19	0.25	0.10
Brick Schlagmann	1395	0.27	14	0.47	0.44
Yellow Brick	1713	0.52	12	0.38	0.31
Lime plaster	1800	0.82	12	0.30	0.13

The exterior climate for the simulations was constructed from a Danish reference year. It should be noted, that the rain has 6 hour intervals between values. The orientation of the external side was set to South West, which is most exposed to wind-driven rain in Denmark [10]. In addition to 6 hour summarized water loads, and South West orientation, the rain exposure coefficient was set to 1, so in periods the bricks were subjected to large rain loads. “Interior” conditions were set constant to 20°C and 50 % relative humidity. The simulations were run for two years, and the latter is displayed in the results. The simulation outputs for the present focus will be the relative humidity in 4 points through the brick – as seen in Figure 1, as well as the liquid moisture content in the entire brick.

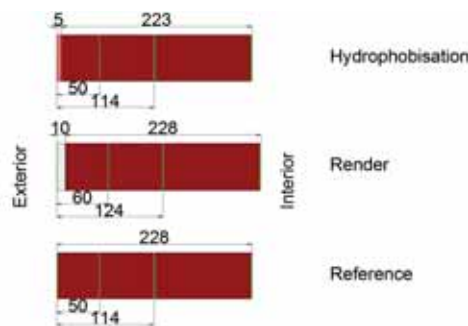


Figure 1. Output locations for Delphin simulations are marked by green lines. Output locations are; exterior, 5 cm from brick exterior, mid-brick and interior side.

The simulations were made for the purpose of surface treatment comparison, and for investigation of the influence of brick type.

### 3. Results

#### 3.1 Laboratory

The Karsten tube measurements yielded results for sorptivity, as shown in Table 3. Specimens with a rendered surface absorbed nearly 25 times more water in 30 minutes, than the reference specimen. Specimens with hydrophobisation barely absorbed any water. The average calculated sorptivities and standard deviations are found in Table 3. It is clear, that the rendered surface exhibits a very high sorptivity, and surface with hydrophobisation a very low sorptivity relative to reference specimens. The results show that both hydrophobisation and render impacts the sorptivity of the brick surface.

Table 3. Average sorptivity and standard deviation for the 3 surface types obtained by Roel Hendrickx' method after Karsten tube experiment and partial immersion experiment.

$\frac{kg}{m^2\sqrt{s}}$	Karsten tube		Partial immersion	
	$S_{average}$	$S_{standard\ deviation}$	$A_{w,average}$	$A_{w,standard\ deviation}$
Reference	0.129	0.070	0.16	0.04
Hydrophobisation	0.009	0.004	0.0004	0.0001
Render	2.229	0.368	0.30	0.03

The obtained results from partial immersion experiment are also displayed in Table 4. For reference and rendered specimens, the curvature, as seen in Figure 2, yielded the implementation of the calculation method described in eq. 5, whereas the hydrophobated specimens displayed a curve, and eq. 6 was used in this case. It is seen, that results differ from Karsten tube, particularly in hydrophobated and rendered specimens, but the same tendency is apparent; that the rendered surface absorbs the largest amount of water, whereas the hydrophobisation again exhibits a largely water repelling behavior. The difference between water absorption coefficient in reference and rendered specimens is less pronounced in the partial immersion experiment. It should be noted, that all reference and rendered specimens displayed water on the top surface, within 1 hour or immersion.

#### 3.1 Simulations

Simulation results of the average water content in the various brick types, with the various surface treatments, are depicted in Figure 3. Figure 4 represent the relative humidity at the output location 5 cm from the exterior side of the brick. Simulation results clearly indicate differences in regards to surface treatment and brick type.

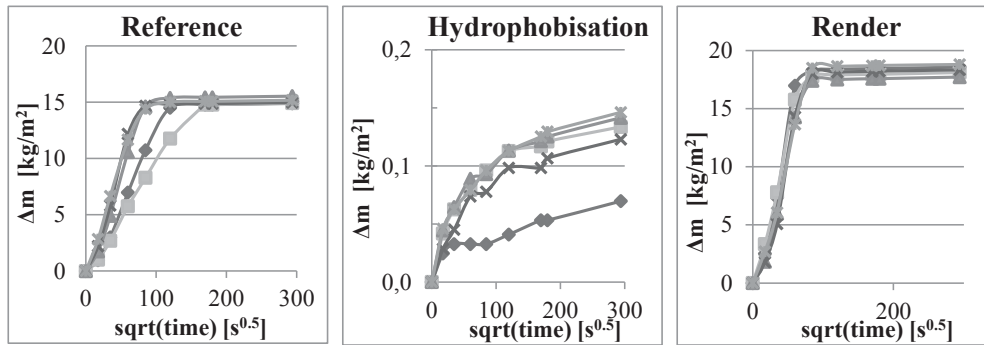


Figure 2. Plots of results from partial immersion experiments.

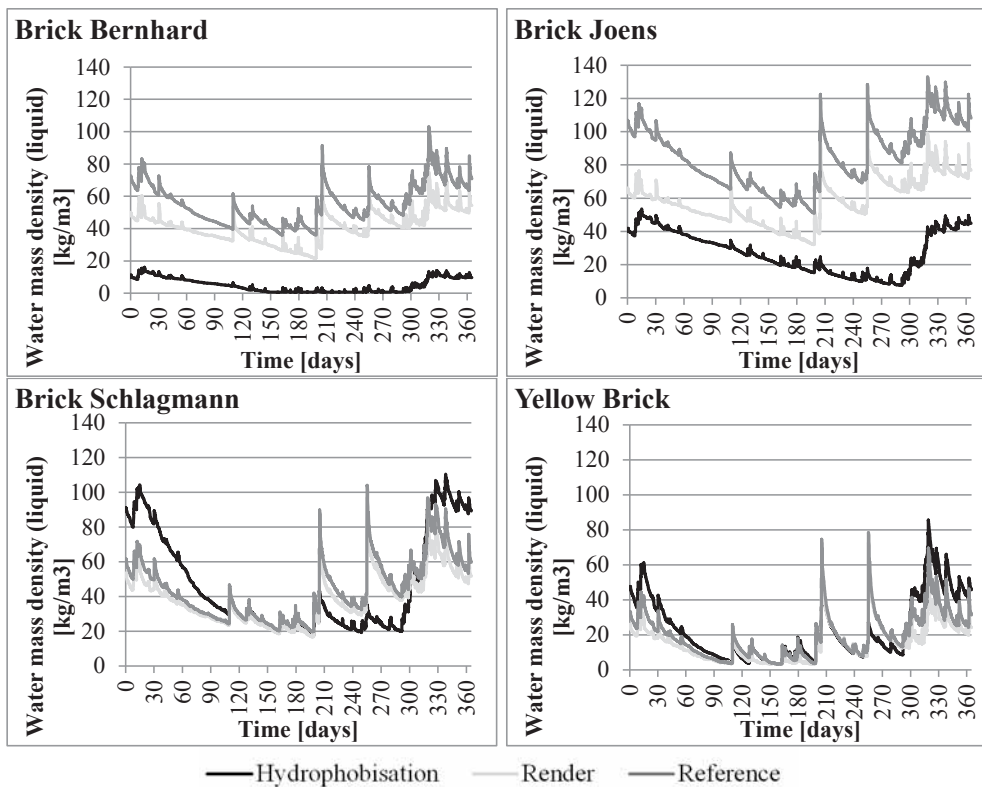


Figure 3. Average moisture content for the 2nd year of simulation and 3 surface types.



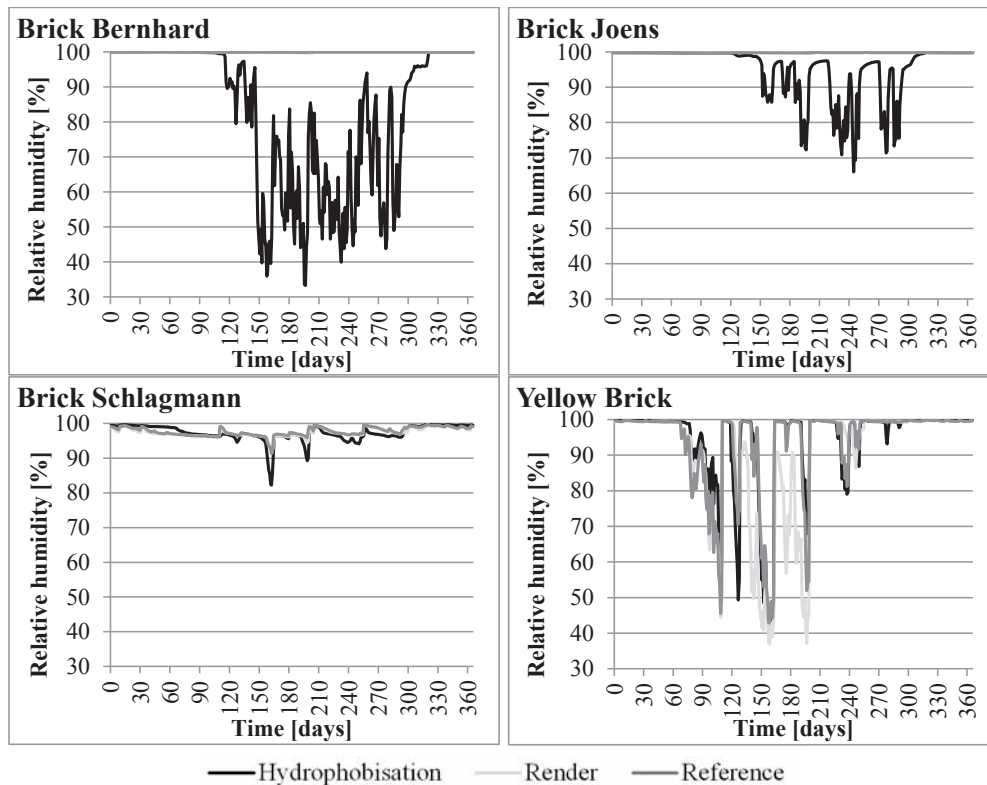


Figure 4. Relative humidity 5 cm from the brick surface for the 2<sup>nd</sup> year of simulation and the 3 surface types.

#### 4. Discussion

The Karsten tube measurements show distinct variation in the absorption in regards to the type of surface. The surface with hydrophobisation treatment hardly absorbed any water – and on average 30 times less than the reference brick. The rendered surface absorbed nearly 25 times the amount of water compared to the reference brick. It was not investigated how the liquid distributed within the render and brick, however in one case a wet spot was observed on the bottom of the brick. The variation in results of the rendered specimens also indicates the unevenness of the surface treatment. The “film” of lime that appears on lime render surfaces, may be able to repel water better in reality with a lesser amount of water load, e.g. rain. The render surface is also assumed to be denser in reality and when executed by a professional, leaving it more weather proof. It should be noted, that the Karsten tube experiments were carried out vertically despite the bricks in real facades would require horizontal Karsten tube measurements. For comparison purposes, this did not cause concern for the results.

The partial immersion experiment showed same tendencies as the Karsten tube experiments for water uptake. Specimens with hydrophobisation treatment absorbed up to 124 times less

water in 24 hours relative to reference specimens. The rendered specimens absorbed a little more than reference specimens, but they also had a larger volume capable of retaining the liquid. The initial water absorption was highest in the rendered specimens. The rendered specimens also exhibited the largest amounts of water on the top surface of the specimen.

The fact that the rendered surface has the highest absorption found in both laboratory experiments seems rather curious. As mentioned, this can partly be due to inhomogeneity appearing as a result of non-professional execution. The extreme results obtained by Karsten tube can partly be explained by the poor adhesion of the tube to the rough surface, as some water may have escaped under the fixation. However, the fact that the absorption in the rendered surface is higher does not necessarily indicate further or faster penetration into the brick. It is possible, that the liquid distributes in render, and which possibly has better drying potential than the brick.

The differences observed between Karsten tube and partial immersion experiments, are assumed obtained partly due to the duration of time. The Karsten tube measurements were performed for only 30 minutes, whereas the partial immersion experiment lasts 24 hours. The initial water uptake in the partial immersion was faster than the Karsten tube.

Simulation results indicated that surface treatments such as either hydrophobisation or render could reduce the liquid moisture content in brick types such as Brick Bernhard or Brick Joens – hydrophobisation had the largest effect of the two treatments. The surface treatments however, seemed to have little to none effect in Brick Schlagmann and Yellow Brick. In the latter, hardly any effect of the surface treatment was observed. In Brick Schlagmann, the hydrophobisation displayed a negative effect in colder periods, but positive in summer.

The calculated relative humidity 5cm from the external brick side was for all brick types and surface treatments found to be very high in winter conditions. As mentioned, the simulations were made as a kind of “worst case” in regards to rain loads, and in winter periods there is only little drying potential. The hydrophobisation treatment again expressed positive impact in the brick types Brick Bernhard and Brick Joens during summer – most prominent in Brick Bernhard. 5 cm from the exterior in Brick Schlagmann no significant effect of the surface treatment was apparent. Within 5cm of the Yellow Brick, the brick seemed to be able to dry out during summer, regardless of the surface treatment.

## **5. Summary and conclusions**

Karsten tube measurements and partial immersion experiment clearly showed the effect of a hydrophobisation surface treatment. Hardly any water was absorbed by specimens with hydrophobisation treatment. The rendered surface absorbed a large amount of water in Karsten tube experiment, but this is assumed to be partly caused by poor execution of rendering, poor adhesion of the tube, and the porosity of the lime render. The tendency of a high initial absorption in rendered specimens was also seen in the partial immersion experiment.

Simulation results made it very clear that the type of brick is a very important parameter when it comes to the effect of surface treatments. However, surfaces with both hydrophobisation and render did express a lower moisture content in Brick Bernhard and Brick Joens. For the

remaining brick types, the moisture content was generally lower than Brick Bernhard and Brick Joens, wherefore the effect is less significant. In both Brick Schlagmann and the Yellow Brick, the specimens with hydrophobisation treatment expressed higher moisture contents in colder periods – yet very little in the Yellow Brick. The conditions within 5 cm inside the brick indicated the effect of hydrophobisation during summer, in cases of Brick Bernhard and Brick Joens, however none effect of surface treatment was clear in Brick Schlagmann or Yellow Brick.

Future research should be done in the field of surface treatments of brick, as it potentially is essential to protect the façade from the climate when installing internal insulation. Research should focus on not only various treatments, but also how the treatments differ in effectiveness on different types of masonry. Surface treatments of mortar in joints should also be researched, as water penetration also occurs through joints. The effect of cracks and micro-cracks on surface treatments is also a highly relevant research area.

## 6. Acknowledgements

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